Water Quality

Water and Sediment Quality of Galveston Bay

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For many years, data relating to the quality of water and sediment have been collected in the Galveston Bay system by a variety of organizations and individuals. The purposes of this study, sponsored by the Galveston Bay National Estuary Program, was to compile these data and to perform a quantitative assessment of water and sediment quality of Galveston Bay and its evolution over time. There were three key objectives:

(1) compilation of a comprehensive data base in machine-manipulative format;
(2) analysis of space and time variation (i.e., "trends") in water and sediment quality parameters; and
(3) identification of probable casual mechanisms to explicate the observed variations.

Their accomplishment provides a foundation for further scientific study of Galveston Bay and for a general understanding of the controls and responses of Bay water quality, which must underlie rational management of the resources of the system.

This study focused on the following categories of parameters: temperature, salinity and related parameters, nutrients, suspended sediments and turbidity, pH, dissolved oxygen, biochemical oxygen demand (BOD) and organics, chlorophyll-a, coliforms, metals, and trace contaminants, including pesticides, PAHs, PCBs, and priority pollutants. This project compiled data from 26 separate data collection programs, including the three major on-going monitoring programs of the state: the Texas Water Commission (TWC) Statewide Monitoring Network, the Coastal Fisheries surveys of Texas Parks and Wildlife Department, and the Shellfish Sanitation program of Texas Department of Health. The project also benefited from the recovery of lost major data sets accomplished in the preceding GBNEP Data Inventory project, including the 1968-72 Galveston Bay Project. Most of the other data sets were keyboarded as a part of the project, and many are practically unavailable elsewhere, existing only in one or a few hard-copy forms.

For each of 73 water-quality parameters and 50 sediment-quality parameters, a master data file was created, each record including the date, sample depth, latitude and longitude of the station, measurement, estimated uncertainty of measurement, and a code identifying the origin of the data. For most parameters, the data record extends back at least two decades, and for a few conventional parameters, back to the 1950s. This compilation is the most extensive and detailed long-term record of water and sediment quality ever assembled for Galveston Bay, and, in our view, is one of the central products of the project.

The study characterized the magnitudes and large-scale distributions in concentration of the study parameters throughout Galveston Bay. These are governed by internal transports together with boundary fluxes and kinetics specific to the parameter. Spatial variation throughout the Galveston Bay system was addressed by aggregating the data into subregions of the bay, using two independent segmentation systems: the TWC Water Quality Segments, used for regulatory purposes, and a system of "Hydrographic Segmentation" devised for this project, based upon present knowledge of the bay and rational physical criteria, such as regions of homogeneity and zones of gradients. All status-and-trends analyses were performed for *both* segmentations, entailing more than 35,000 separate statistical analyses.

Substantial gradients across the bay are a normal feature of salinity structure, declining on average from values about 30 ppt at the inlets to the sea to about 3 ppt near principal points of inflow, such as the Trinity River. Vertical stratification of bay waters is slight, by estuarine standards, generally averaging less than 0.6 ppt/m, and averaging less than 0.3 ppt/m over about half of the bay area, with no correlation with water depth. Temperature, on the other hand, is much more homogeneous with little systematic stratification, the seasonal signal being the principal source of variation.

Dissolved oxygen (DO) is generally high throughout Galveston Bay, averaging near-saturation through large areas of the bay, with frequent occurrence of supersaturation. Exceptions to this are in poorly flushed tributaries subjected to inflow and waste discharges, most notorious of which is the Houston Ship Channel. This is displayed in Figure 1 which depicts the period-of-record mean values of DO deficit for each of the hydrographic segments used in this study. Trends in DO deficit are displayed in the same format in Figure 2: in this figure, a *probable* increasing or decreasing trend means that the 95% confidence bounds on the slope of the time regression have the same sign, positive or negative, respectively. A *possible* increasing or decreasing trend means that the 80% confidence bounds have the same sign. Since each hydrographic segment contains its own data sets and is analyzed separately, a pattern of consistent trends from segment to segment in a region of the bay not only reinforces but strengthens the statistical "reality" of the computed trend.

Contaminants, including BOD, oil and grease, coliforms, metals, and trace organics, show elevated levels in regions of runoff and waste discharge, with generally the highest values in the upper Houston Ship Channel (HSC) and generally low values in the open bay waters. The influx of conventional pollutants as a mass load from both point source discharges and inflows peaked in the 1960s and has declined since. One prominent reason is the implementation of advanced waste treatment, for example, a 20-fold reduction in BOD loading since about 1970. Within the upper

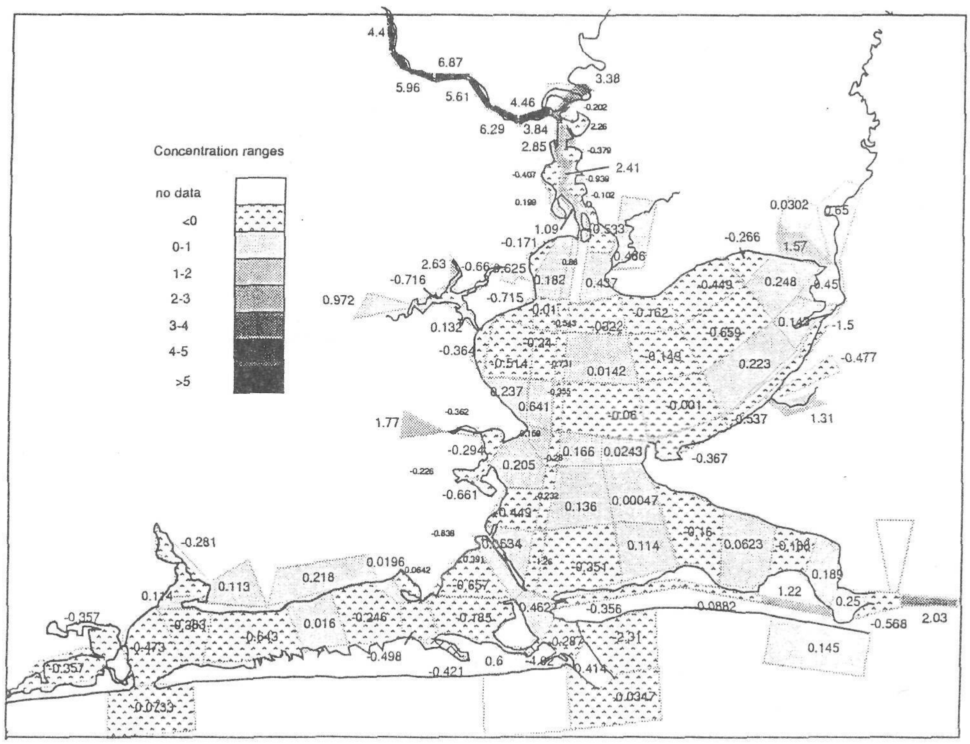

Figure 1. Average concentrations of dissolved oxygen deficit (WQDODEF) within upper 0.5 m in Galveston Bay.

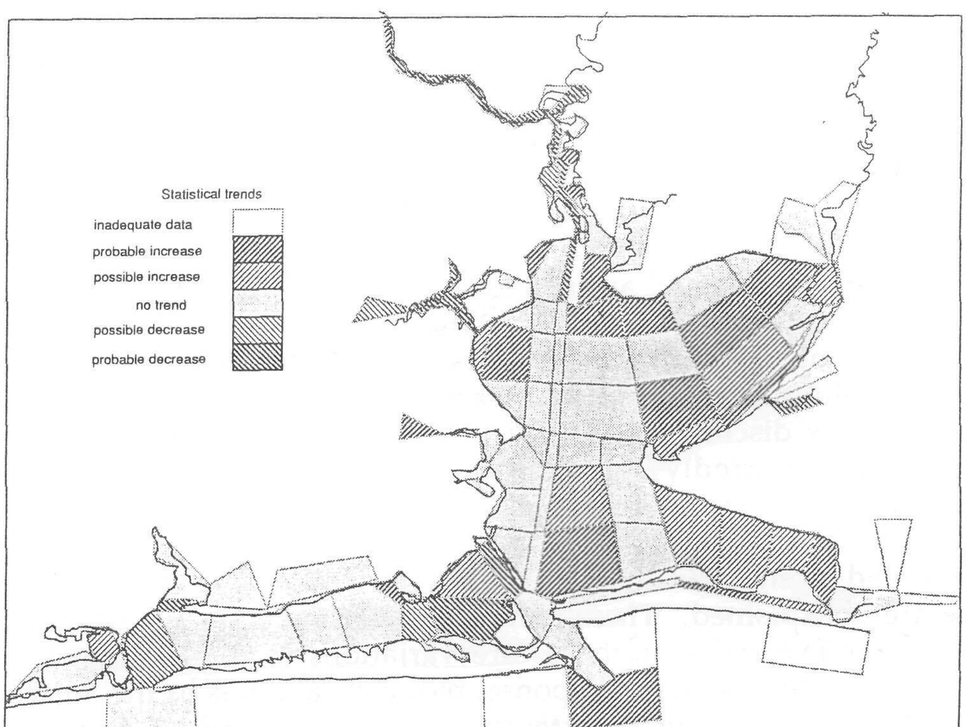

Figure 2. Statistical trends over period of record for dissolved oxygen deficit (WODODEF) in upper 0.5 m in Galveston Bay.

HSC, the DO deficit has been reduced about 4 ppm in the past 20 years. In addition, there has been a decrease in mass loading from the river and stream inflows due to a combination of improved waste treatment, altered land use, and impoundments on the principal rivers and the concomitant entrapment of fine-grain sediments. The actual DO deficit data and the computed regressions for two specific segments in the upper Houston Ship Channel are shown in Figure 3.

The study disclosed major alterations in water quality in the system, including:

- a decline in salinity over the three-decade period of record, of about 0.1-0.2 ppt per year;

- a decline in water temperature, especially in the summer, at a nominal rate of 0.05°C/yr;

- a decline in total suspended solids (TSS) throughout the system, Figure 4, to levels roughly one-third of those 25 years ago;

- declines in nitrogen and phosphorus concentrations throughout the bay over the past two decades, total ammonia N on the order of 0.1 ppm/yr, total nitrate on the order of 0.01 ppm/yr, and total phosphorus on the order of 0.05 ppm/yr;

- declines in total organic carbon (TOC) to levels about one-third of the concentrations of the mid-1970's, and in chlorophyll-a to levels about one-half of those a decade ago; and

- declines in most of the metals, both in water and sediment, in areas of maximal concentrations, especially the Houston Ship Channel, where the rates of decline per decade for sediment concentrations of chromium, mercury and zinc are a factor of two, copper and nickel a factor of three, and arsenic, cadmium and lead an order of magnitude.

In summary, the geographical problem areas of Galveston Bay are where we expect them to be: in regions of intense human activity, including urban areas, points of surface runoff, waste discharges, and shipping. The quality of the bay is generally good (perhaps unexpectedly), and where it is degraded there is a trend of improvement, in many cases substantial.

The above-noted trends in hydrographic parameters such as salinity and temperature are unexplained. There is no clear association of the decline in salinity with inflow. Our favored hypotheses are variations in the time signal of inflow events and the associated salinity response, reduced salinities in the adjacent Gulf of Mexico, or reduced intensity of interaction between estuary and Gulf waters. Hypothetical causes for the decline in temperature include an alteration in climate (e.g., air temperature, wind, cloud cover), and altered interaction with the Gulf of

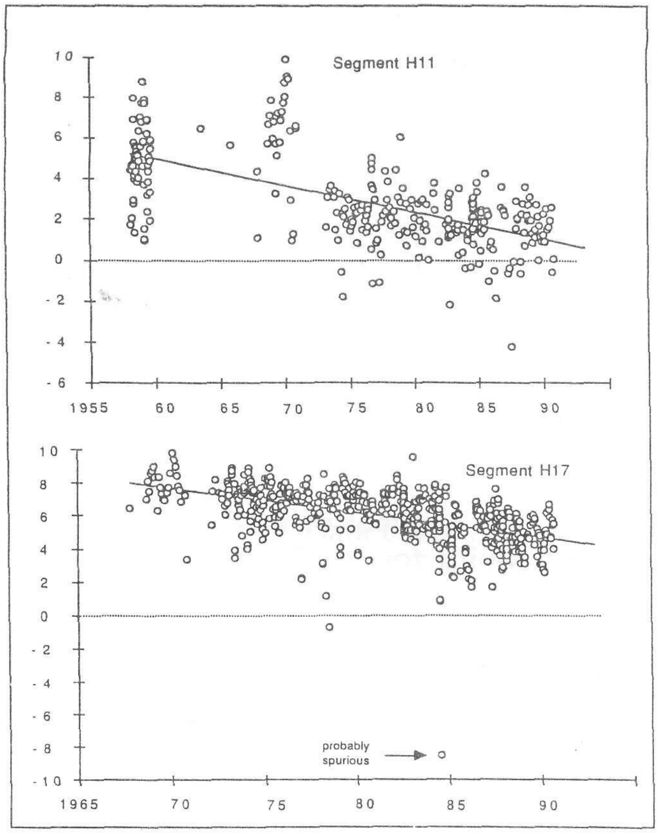

Figure 3. Dissolved oxygen deficit (WQDODEF) trends in confined reach of Houston Ship Channel, Segments H11 and H17 (upper 0.5 m).

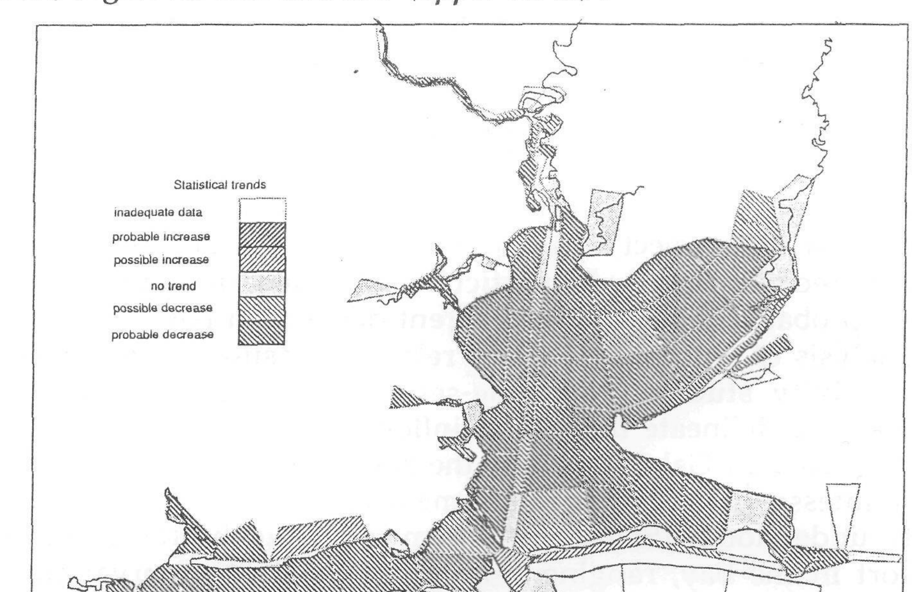

Figure 4. Statistical trends over period of record for total suspended solids (WQXTSS) in Galveston Bay.

Mexico. Further studies of these phenomena are recommended for the insight they could provide into the controls of the bay system.

The greatest problem of concern to us is the systematic decline in nutrients, suspended solids, and chlorophyll. We favor the hypothesis that TSS decline is caused by a general reduction of loading to the bay, due to advanced waste treatment, entrapment within reservoirs, and changing land use. Because nitrogen and phosphorus have an affinity for fine-grain particulates, their association with TSS is more than coincidental, and their declines may be due to the same causes. We note the associated declines in chlorophyll and organic carbon. Few inferences can be more fraught with hazard than assigning causality to correlated trends. On the other hand, the pathway from nutrient-particulate loads through receiving-water concentrations to algal uptake thence assimilation into the food chain is fundamental to the estuarine ecosystem. That a correlated trend seems to be manifest in indicators of every element of this pathway, and that this trend points toward a declining productivity for the bay, are sufficient to warrant increased attention.

Several of the recommendations addressed the problem of data collection and data management in Galveston Bay. These included a plea for recognition of data collection as a collective enterprise, with a certain degree of scientific altruism. Few programs can afford the investment of long-term, comprehensive, intensive data collection in a system such as Galveston Bay. We must depend upon the use of data collected by different agencies for perhaps different purposes, and utility of the data should be maximized. In particular, the investment in putting a sampling crew on a specific station far outweighs the incremental cost of acquiring additional measurements, perhaps peripheral to the principal objective of the sampling. We also noted the necessity for both continuity in time and continuity in space, as well as the need for maintenance of a long period of sampling.

This study approached water-quality analysis from a statistical viewpoint. The data base assembled in this project will support much more detailed and sophisticated analyses. We recommended, in particular, detailed mass-budgeting studies to determine the probable cause of the apparent declines in particulates and nutrients, additional analysis of chlorophyll-a and related measurements in association with *in situ* productivity studies, and time-series and response analysis of salinity variability to better delineate the role of inflow and other hydrographic factors. In an estuary as turbid as Galveston Bay, the role of sediments in suspension and in the bed is quintessential. Yet, every element of the sediment transport process is inadequately understood. Sediment dynamics should be the focus of a renewed research effort in the bay, ranging from more detailed observation on grain-size spectrum and its effects, to biokinetic processes operating within the sediment itself.

Products of the project include the final report (Ward and Armstrong, 1992a), an extended technical report of some 1500 pages documented all of the statistical results and the details of the analyses (Ward and Armstrong, 1992b), and a users manual for the digital data base (Ward and Armstrong, 1992c), including the data base itself on 24 high-density microdiskettes.

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Water Quality Trends for the Houston Ship Channel

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While there have been indications that water quality in the Houston Ship Channel is improving, temporal trends have not been adequately verified and documented. An investigation was made utilizing ambient monitoring data to make inferences on water quality trends for selected parameters. The purpose of this paper is to present results of this investigation. The study findings are more thoroughly discussed by Crocker et al. (1992).

Twenty-one water quality parameters were assessed including conventional parameters (DO, TSS, fecal coliforms, BOD, and TOC), nutrients (ammonia, nitrate, nitrite, Kjeldahl nitrogen, orthophosphate, and total phosphorus), and heavy metals (arsenic, cadmium, chromium, copper, lead, mercury, nickel, selenium, silver, and zinc). In addition, heavy metals and PCBs in sediment were assessed, although data are more limited for these parameters. Concentrations over the last 10-20 years were assessed over time using statistical correlation (Pearson, Spearman and Kendall tau-b correlations). The primary database used was the Texas Water Commission state monitoring network (SMN) data. The five Ship Channel stations assessed are located at Morgans Point at the mouth, proceeding upstream to Channel Marker 120, San Jacinto Monument, at the Greens Bayou confluence, and the turning basin (the upstream extent of the Ship Channel). These station locations are shown in Figure 1.

Table 1 presents a summary of water quality trends for the Ship Channel. Table 2 shows water quality trends for the Ship Channel by station. If greater than 95% probability was found using all three statistical tests, the parameter was assumed to be *significantly* increasing or declining; at 90% or greater, *possibly* increasing or decreasing; and at less than 90%, *no changes* in concentration over time. In general, there was good agreement between the statistical tests.

As would be expected, trends differed by parameter and by station. Most encouraging were the apparent declining trends at all or most of the five stations for TOC, TSS, fecal coliform bacteria, ammonia, orthophosphate, total phosphate, total arsenic, and total copper. The data sets analyzed included remarked data (e.g., "<" or ">"). Therefore, to some degree apparent trends may have been influenced by lowering of detection levels over time rather than actual reductions in concentration. Apparent increasing trends were found for nitrate and nitrite. Apparent declining trends were found at one or two of the stations located furthest upstream, with no significant changes at downstream stations for total cadmium, total mercury, total nickel, and total zinc. Trends for total silver varied considerably

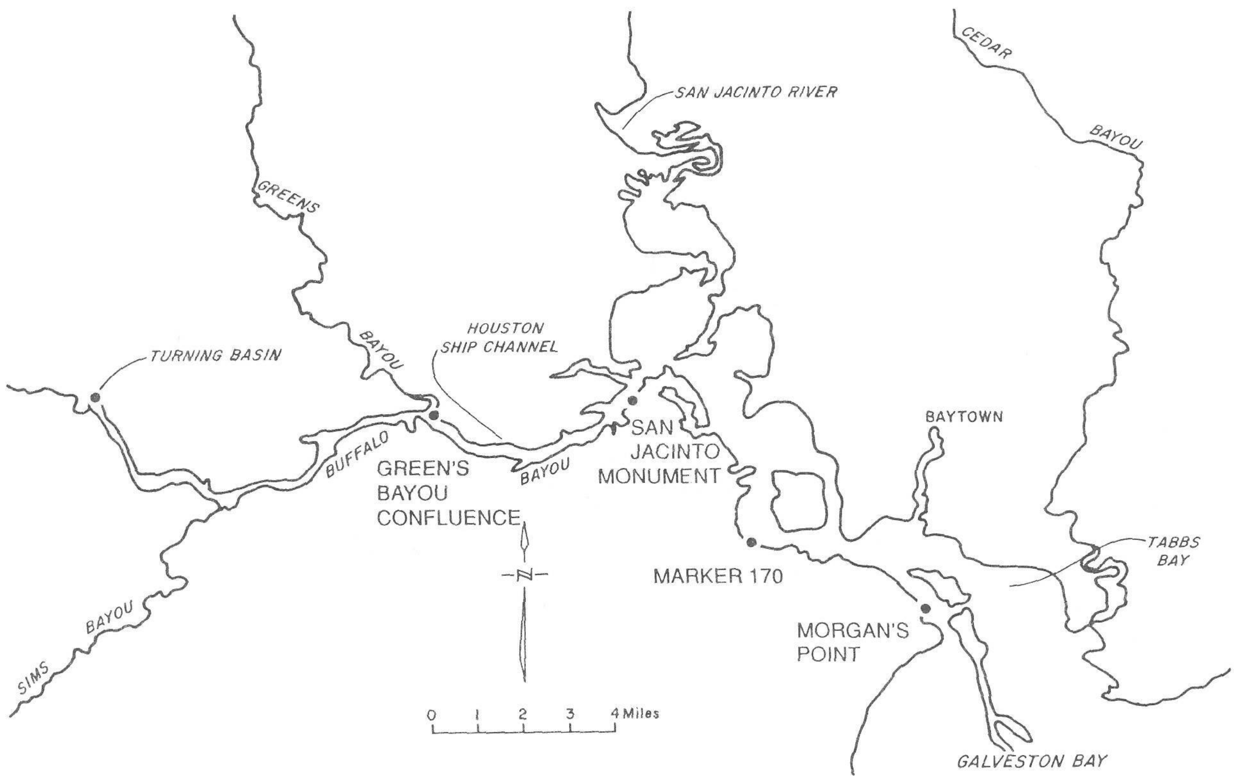

Figure 1. Locations of ambient monitoring stations.

Table 1. Water Quality Trends for the Houston Ship Channel: Summary.

Improving	Differs by Location	No Change	Worsening
Total Organic Carbon	Dissolved Oxygen*	Total Chromium	Nitrate
Total Suspended Solids	Biological Oxygen*	PCBs in Bottom Sediment	Nitrite
Fecal Coliform Bacteria	Kjeldahl Nitrogen*		Selenium
Ammonia	Total Lead		
Organophosphate	Total Silver		
Total Phosphate	Cooper in Bottom Sediment		
Total Arsenic	Lead in Bottom Sediment		
Total Copper	Zinc in Bottom Sediment		
Total Cadmium*			
Total Mercury*			
Total Nickel			
Total Zinc*			
Arsenic in Bottom Sediment			
Cadmium in Bottom Sediment*			

Table 2. Water Quality Trends for the Houston Ship Channel: By Station.

Parameter /Location	Trend*
Dissolved Oxygen	
Turning Basin	↑
Greens Bayou Confluence	↑
San Jacinto Monument	↑
Channel Marker 120	~↓
Morgans Point	↓
Total Suspended Solids	
Turning Basin	↓
Greens Bayou Confluence	↓
San Jacinto Monument	↓
Channel Marker 120	↓
Morgans Point	--
Fecal Coliforms	
Turning Basin	↓
Greens Bayou Confluence	↓
San Jacinto Monument	~↓
Channel Marker 120	~↓
Morgans Point	--
BOD 5-Day	
Turning Basin	↓
Greens Bayou Confluence	--
San Jacinto Monument	--
Channel Marker 120	~↑
Morgans Point	↑
Total Organic Carbon	
Turning Basin	↓
Greens Bayou Confluence	↓
San Jacinto Monument	↓
Channel Marker 120	↓
Morgans Point	↓
Ammonia-Nitrogen	
Turning Basin	↓
Greens Bayou Confluence	↓
San Jacinto Monument	↓
Channel Marker 120	↓
Morgans Point	↓
Nitrate	
Turning Basin	↑
Greens Bayou Confluence	↑
San Jacinto Monument	↑
Nitrate (More)	
Channel Marker 120	↑
Morgans Point	↑
Nitrite	
Turning Basin	~↑
Greens Bayou Confluence	↑
San Jacinto Monument	~↑
Channel Marker 120	~↑
Morgans Point	--
Total Kjeldahl Nitrogen	
Turning Basin	↓
Greens Bayou Confluence	↓
San Jacinto Monument	↓
Channel Marker 120	--
Morgans Point	↑
Orthophosphate	
Turning Basin	↓
Greens Bayou Confluence	↓
San Jacinto Monument	↓
Channel Marker 120	↓
Morgans Point	~↓
Total Phosphorous	
Turning Basin	↓
Greens Bayou Confluence	↓
San Jacinto Monument	↓
Channel Marker 120	↓
Morgans Point	↓
Total Cadmium	
Turning Basin	~↓
Greens Bayou Confluence	~↓
San Jacinto Monument	↓
Channel Marker 120	--
Morgans Point	--
Total Chromium	
Turning Basin	--
Greens Bayou Confluence	--
San Jacinto Monument	--
Channel Marker 120	--
Morgans Point	--

Parameter/ Location	Trend*
Total Copper	
Turning Basin	↓
Greens Bayou Confluence	↓
San Jacinto Monument	↓
Channel Marker 120	↓
Morgans Point	↓
Total Lead	
Turning Basin	↓
Greens Bayou Confluence	--
San Jacinto Monument	~↑
Channel Marker 120	--
Morgans Point	--
Total Mercury	
Turning Basin	↓
Greens Bayou Confluence	--
San Jacinto Monument	--
Channel Marker 120	--
Morgans Point	--
Total Nickel	
Turning Basin	↓
Greens Bayou Confluence	--
San Jacinto Monument	--
Channel Marker 120	~↓
Morgans Point	--
Total Selenium	
Turning Basin	--
Greens Bayou Confluence	--
San Jacinto Monument	~↑
Channel Marker 120	~↑
Morgans Point	--
Total Silver	
Turning Basin	~↓
Greens Bayou Confluence	~↑
San Jacinto Monument	~↑
Channel Marker 120	--
Morgans Point	~↑

Parameter/ Location	Trend*
Total Zinc	
Turning Basin	↓
Greens Bayou Confluence	~↓
San Jacinto Monument	--
Morgans Point	--
Arsenic in Bottom Sediment	
Turning Basin	↓
Greens Bayou Confluence	--
San Jacinto Monument	~↓
Morgans Point	↓
Cadmium in Bottom Sediment	
Turning Basin	↓
Greens Bayou Confluence	--
San Jacinto Monument	--
Morgans Point	--
Copper in Bottom Sediment	
Turning Basin	~↓
Greens Bayou Confluence	~↑
San Jacinto Monument	--
Morgans Point	--
Lead in Bottom Sediment	
Turning Basin	↓
Greens Bayou Confluence	--
San Jacinto Monument	~↑
Morgans Point	~↑
Zinc in Bottom Sediment	
Turning Basin	↓
Greens Bayou Confluence	~↑
San Jacinto Monument	--
Morgans Point	--
PCBs in Bottom Sediment	
Turning Basin	--
Greens Bayou Confluence	--
San Jacinto Monument	--
Morgans Point	--

Legend	
Apparent Increasing Trend	*↑
Apparent Decreasing Trend	~↑
Possible Increasing/ Decreasing Trend	~↑/~↓
Trend	-- =

The Impacts of Marinas on the Water Quality of Galveston Bay

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Water quality impacts from marinas along the Gulf coast of the United States are poorly understood. It has been documented in other areas of the country that marinas with their associated boats can be a large source of pollutants, including heavy metals, fecal coliforms, and nutrients (NCDEHNR 1991). Improperly designed marinas can also reduce flushing and, during times of minimal water movements, concentrate pollutants and cause serious environmental harm, including fish kills. Galveston Bay and, in particular, the Clear Lake area contains a very high concentration of recreational vessels. Approximately 40 marinas with 9,171 wet slips were documented in Galveston Bay during 1987 (Ditton et al., 1988). This represents 62.9% and 29.9% of the total Texas coastal wet slips and marinas, respectively. Within the Clear Lake area alone there were an estimated 22 marinas with 6358 wet slips (Hollin, 1992). Until recently there were few locations to pump out boat sewage and, consequently, much of the boat sewage was directly discharged into Galveston Bay and/or Clear Lake. However, recently a private entrepreneur has built both portable and stationary sites in Clear Lake (Maritime Sanitation, 1992). Evaluating the impact of pollution from Galveston Bay marinas is the purpose of this project. Hopefully, this information could be used to develop reasonable management strategies for siting, construction, and maintenance of coastal marinas. One of the primary objectives of this study was to study and characterize the current environmental quality and determine the extent of impacted areas located in and adjacent to marinas. The information in this report reflects the preliminary findings of this study.

Site Description

Four recreational marinas and one boat canal subdivision were studied during May and July 1992. These included the Galveston Yacht Club, Lafayette Landing, Houston Yacht Club, South Shore Harbor, and Jamaica Beach. Locations of the marinas are shown in Figure 1. A brief description of each marina is provided in Table 1.

There are other potential sources of pollutants in Clear Lake and Galveston Bay. Various point source discharges are located within Clear Lake and may impact the water quality in areas adjacent to the South Shore Harbor and Lafayette Landing marinas. Within Clear Lake, TWC segment 2425 there are four permitted domestic sewage treatment plant outfalls with permitted discharge levels of 1.04 MGD (TWC, 1992). Two of these facilities discharge indirectly into adjacent tributaries. There are 11 industrial discharges with final permitted discharge levels of .05 MGD. The majority of this volume is attributable to cooling water discharge from a power plant. Based on

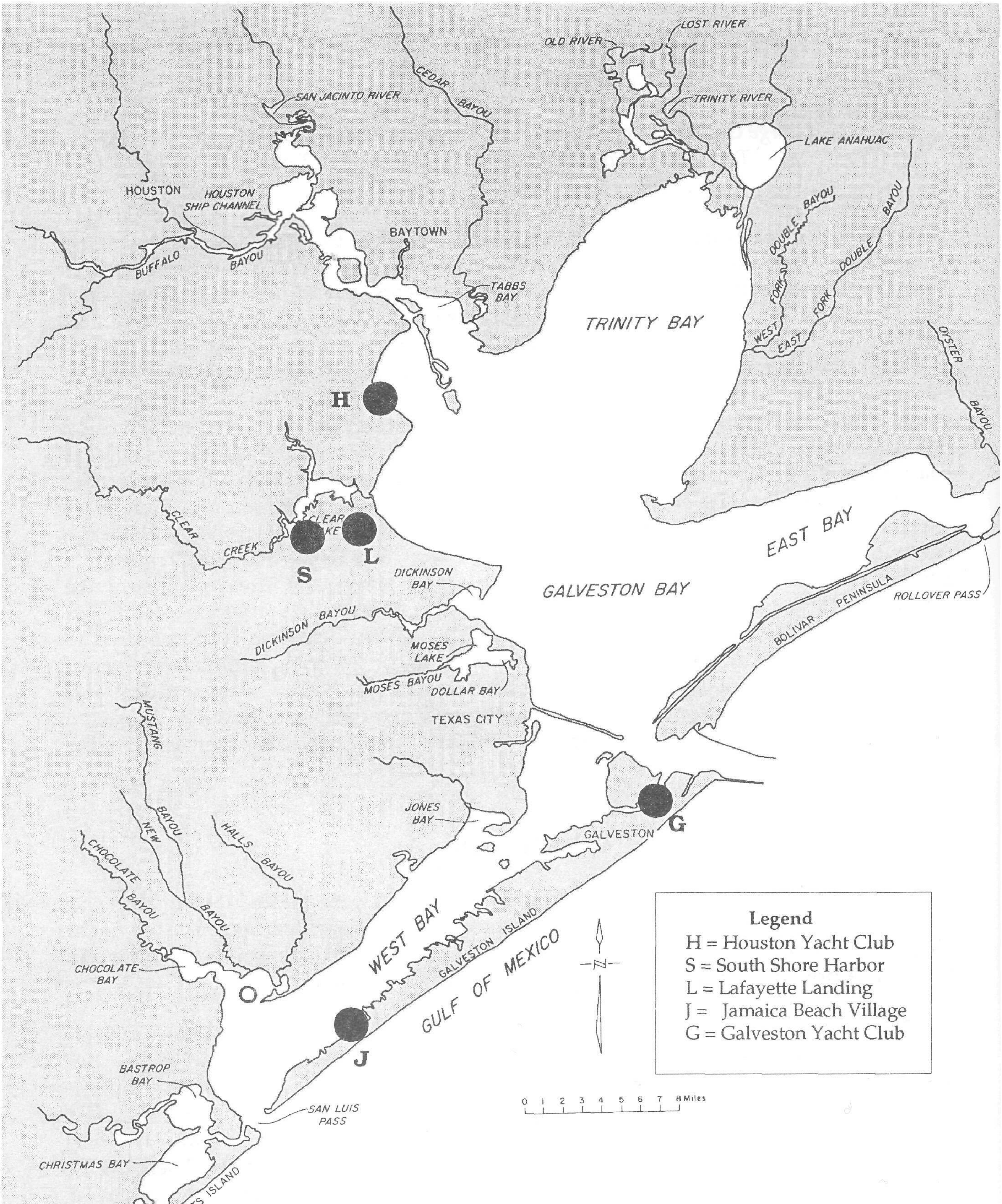

Figure 1. Location of marinas included in the study.

TWC self-reporting data, the average BOD loading into segment 2425 between 1985 and 1989 was 11.85 lbs/d. There are also nine permitted domestic outfalls in the upstream Clear Creek tidal segment, TWC segment 1101, with final permitted flows of 18.23 MGD (TWC, 1992). Based on TWC self reporting data, the average BOD loading into segment 1101 between 1985 and 1989 was 172.29 lbs/d. There are also boat maintenance facilities at the Lafayette Landing Marina where paint stripping and painting of boat hulls occurs. During the study period, South Shore Harbor was the only marina facility in Clear Lake that possessed a pumpout facility for recreational boats.

Table 1. General site description for each marina.

Marina Study Site	Surface Area (acres)	Average Depth (ft)	Number of Boats Power / Sail	Number of Slips	Number of Boats per Acre	Age of Marina Years
Jamaica Beach	1153	4	379 / 37	496	.36	Unknown
Galveston Yacht Club	25	10	215 / 115	520	13.2	25
Houston Yacht Club	43	9	25 / 245	519	6.3	65
South Shore Harbour	65	8	450 / 175	1007	9.6	10
Lafayette Landing	16	10	315 / 55	420	23.1	5

There are six domestic sewage treatment outfalls and three industrial outfalls located in upper Galveston Bay, TWC segment 2421 (TWC, 1992). The total final permitted effluent level for domestic and industrial dischargers in this segment is 12.59 and 0.20 MGD, respectively. Based on TWC self-reporting data the average BOD loading into segment 2421 between 1985 and 1989 was 338.10 lbs/d. The Bayport Channel, TWC segment 2438, is located near the Houston Yacht Club and has five permitted industrial outfalls with final permitted discharge levels of 15.81 MGD. There are also boat maintenance facilities at the Houston Yacht Club where paint stripping and painting of boat hulls occurs.

The Galveston Yacht Basin is located in lower Galveston Bay. In lower Galveston Bay, TWC segment 2439, there are 10 domestic outfalls and 16 industrial outfalls with final permitted discharge levels of 10.58 and 149.61 MGD respectively (TWC, 1992). Based on TWC self-reporting data, the average BOD loading into segment 2439 between 1985 and 1989 was 1709.57 lbs/d. There are also boat maintenance facilities at Galveston Yacht Club where paint stripping and painting of boat hulls occurs.

The Jamaica Beach subdivision is located in West Bay. This subdivision contains an extensive "finger canal" system where bay-side homes are located. Almost all of the boats seen at this location were stored in boat lifts above the water. There are 12 domestic and three industrial outfalls permitted in West Bay (TWC, 1992). The final permitted discharge levels for domestic and industrial sources are 13.68 and 0.07 MGD respectively. Based on TWC self-reporting data, the average BOD loading into segment

2424 between 1985 and 1989 was 175.16 lbs/d. A sewage treatment plant at Jamaica Beach discharges an average of 0.045 MGD into West Bay (TWC self-reporting data).

Methods

During May and July 1992, surface water and recently deposited sediment samples were collected from four locations at each marina site. These locations included an inside station (furthest away from outlets to adjacent water bodies), an entrance station at the opening of the marina, a near-field station (within 0.25 miles from the entrance), and a far-field site (usually ≥ 0.5 miles from the entrance). Dissolved arsenic, lead, and copper were measured in each of the water samples to compare to state aquatic life chronic standards. In addition, arsenic, lead, and copper were measured in sediment samples. Data on dissolved oxygen and fecal coliforms were obtained from each site. These data were compared to state water quality standards for each segment. *In situ* measurements of dissolved oxygen, temperature, and salinity and tide stage were obtained using stationary Hydrolab datasondes and/or portable Scout meters. This information was used to obtain preliminary estimates of flushing times for each marina or canal using EPA methodology (EPA, 1985).

Results

The configuration of each marina site varied greatly (Table 1). For example the Jamaica Beach subdivision canal system was much larger in terms of surface area than any other marina. The greatest concentration of boats per unit area occurred at Lafayette Landing. Flushing rates for each site also varied greatly (Table 2).

Table 2. Estimated flushing rate for marinas and canals.

Marina	R	D	Tc	A	b	L	H	Avg. Depth (m)	Tf (hours)	Tf (days)
Galveston Yacht Club	0.1	0.01	24	101150	0.5	2.9	3.2	3.0	1859.9	77.5
Jamaica Beach	0.2	0.01	24	5E+06	0.5	1.1	1.4	1.2	606.2	25.3
South Shore Harbour	0.2	0.01	24	262990	0.5	2.3	2.6	2.4	1196.5	49.9
Lafayette Landing	0.1	0.01	24	64736	0.5	2.9	3.1	3.0	2474.1	103.1
Houston Yacht Club	0.1	0.01	24	173978	0.5	2.6	2.9	2.7	1675.7	69.8

Tf = TcLogD(AL+bAR)/(AH))
Tc = tidal cycle, high tide to high tide (hours)
D = desired dilution factor
b = return flow factor (dimensionless)
H = average depth at high tide (m)
Tf = flushing time (hours)
A = surface area of marina (m2)
R = range of tide (m)
L = average depth at low tide (m)

The flushing rate was highest at the shallowest marina, Jamaica Beach. It should be noted that the simplistic model used to generate flushing rates may have underestimated flushing at the Houston Yacht Club and Galveston Yacht Basin. Both of these facilities possess bulkheads with elevated bottoms, which provide additional flushing. The small tidal amplitude greatly lengthened the time required to completely flush each marina.

There was a general decrease in dissolved oxygen as one progressed toward the inner part of each marina system during May 1992 (Figs. 2 and 3). This pattern was less pronounced during July 1992. The lowest levels were observed at the South Shore Harbor inner station. These were far below the ambient levels recorded at the far-field station and at adjacent ambient monitoring stations. In addition, recorded values at Jamaica Beach and South Shore Harbor at the inner stations violated state water quality standards for dissolved oxygen (4 mg/l D.O.). Most far-field stations were similar to recent historical ambient monitoring levels for that segment (Table 3).

There was a general increase in fecal coliform levels as one progressed toward the inner part of each marina system (Fig. 4). The highest levels observed were seen at the Clear Lake marinas, Lafayette Landing, and South Shore Harbor inner stations. These levels were far above the ambient levels recorded at the far-field station and at adjacent ambient monitoring station. State water quality standards for fecal coliforms were exceeded at these inner stations. State shellfish standards (14 colonies/100 ml) were violated at the Houston Yacht Club. Most far-field stations were similar to recent historical ambient monitoring levels for that segment (Fig. 4 and Table 3).

Dissolved arsenic levels were generally low throughout the survey period and never exceeded state chronic criteria (80 ug/l dissolved arsenic) (Fig. 5). No pattern was discernible due to the lack of values above the detection limit. Although sediment samples never exceeded the state 85th percentile for sediment arsenic, there was nonetheless an apparent increasing trend of arsenic contamination toward the inner stations of each marina (Fig. 6). This suggests that long term accumulation of arsenic in sediments may be occurring at these marinas.

Dissolved lead levels fluctuated throughout the survey period and periodically exceeded state chronic criteria (5.6 ug/l dissolved lead) (Fig. 7). Interpretation of samples collected at the Galveston Yacht Club and Jamaica Beach during May 1992 are difficult due to the high detection limits that exceeded the state chronic criteria for dissolved lead. Overall, it did appear that Jamaica Beach had the highest dissolved lead levels during July 1992. Highest dissolved lead levels were observed at the marina stations (inside and entrance). South Shore Harbor dissolved lead level were consistently low. Many sediment samples exceeded the state 85th percentile for sediment lead (Fig. 8). There was also an apparent increasing trend of copper contamination toward the inner stations of each marina. This suggests that long term accumulation of lead in sediments may be occurring at these marinas. The least contaminated sediment was collected from Jamaica Beach. This was inconsistent with

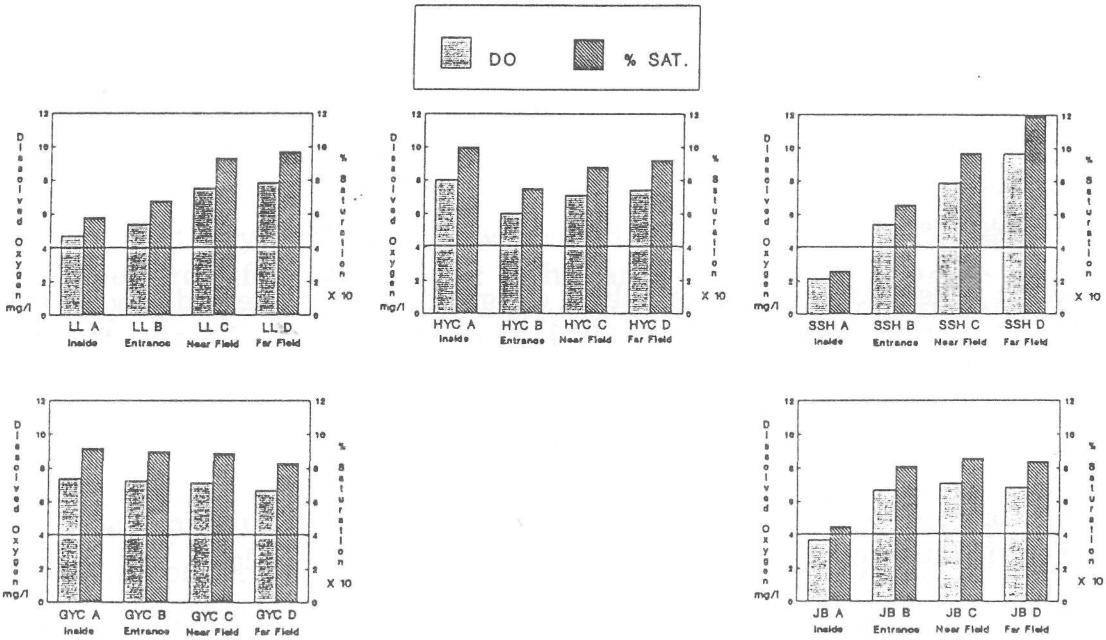

Figure 2. Dissolved oxygen and percentage saturation levels measured at one foot depth during sediment and water sample collection at all marina sites in May 1992. Grid line at 4 mg/L indicates the State water quality standard for the stream segment in which the marina is located.

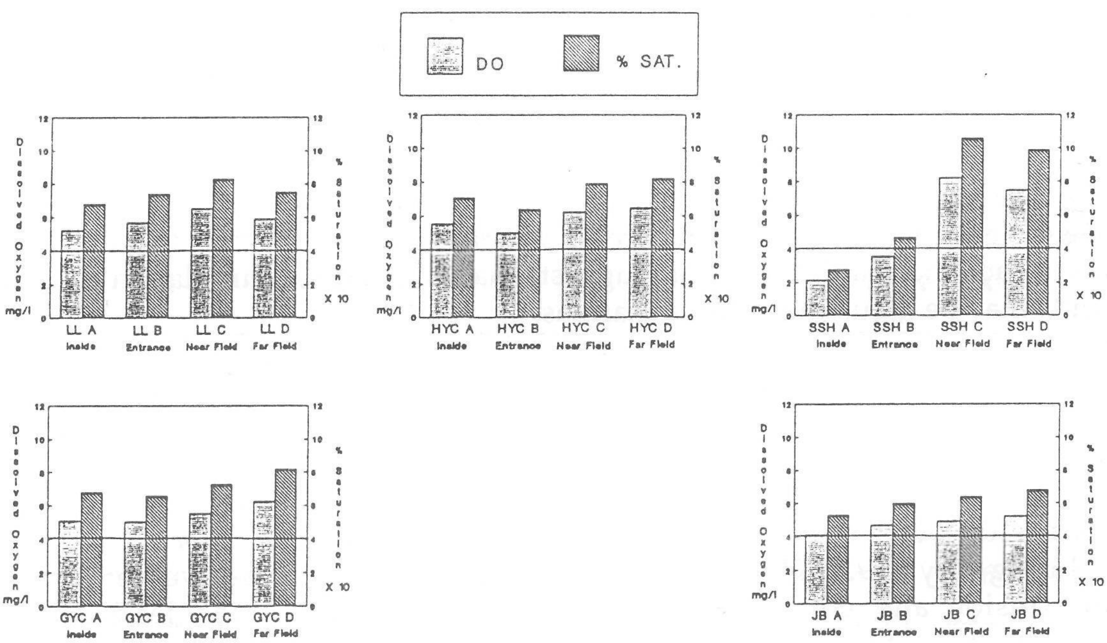

Figure 3. Dissolved oxygen and percentage saturation levels measured at one foot depth during sediment and water sample collection at all marina sites in July 1992. Grid line at 4 mg/L indicates the State water quality standard for the stream segment in which the marina is located.

Table 3. Routine monitoring stations located closest to marina study sites.

Marina Study Site	Station Number & Description	Date	Fecal Coliform (col./100 ml)	Dissolved Oxygen (mg/l)
Galveston Yacht Club	2439.0450	02/19.92	<10	8.9
	Galveston Channel	11/13/91	<10	10.4
	mid-channel between	08/06/91	40	5.4
	Seawolf Park &	05/02/91	<10	6.7
	Coast Guard Station	02/28/91	10	8.5
		11/13/90	<10	9.2
	2439.0300	05/02/91	20	6.5
	Galveston Channel	02/28/91	<10	8.8
	at FLR 2	11/13/90	<10	8.3
		08/15/90	<10	6.4
		05/09/90	<10	8.6
		02/13/90	<10	7.6
Jamaica Beach	2424.0100	03/26/92	<10	7.7
	West Bay at	12/05/91	<10	8.9
	Caracahua Reef	09/10/91	<10	6.4
		06/06/91	10	6.7
		03/06/91	<10	8.8
		12/31/90	<10	8.7
Lafayette Landing	2425.0100	06/04/92	380	5.4
	Clear Lake at	03/12/92	75	9.7
	SH 146	12/30/91	340	9.6
		09/04/91	50	5.9
		06/04/91	10	7.0
		03/05/91	60	9.8
South Shore Harbour	2425.0200	06/04/92	1300	5.1
	Clear Lake	03/12/92	60	8.7
	at CM 17	12/30/91	1900	8.4
		09/04/91	20	5.8
		06/04/91	30	7.5
		03/05/91	80	11.2
Houston Yacht Club	2421.0700	06/04/92	120	7.0
	Galveston Bay at	03/12/92	10	11.1
	HSC 76	12/30/91	200	9.8
		09/04/91	30	8.2
		06/04/91	<10	5.8
		03/05/91	20	6.2*

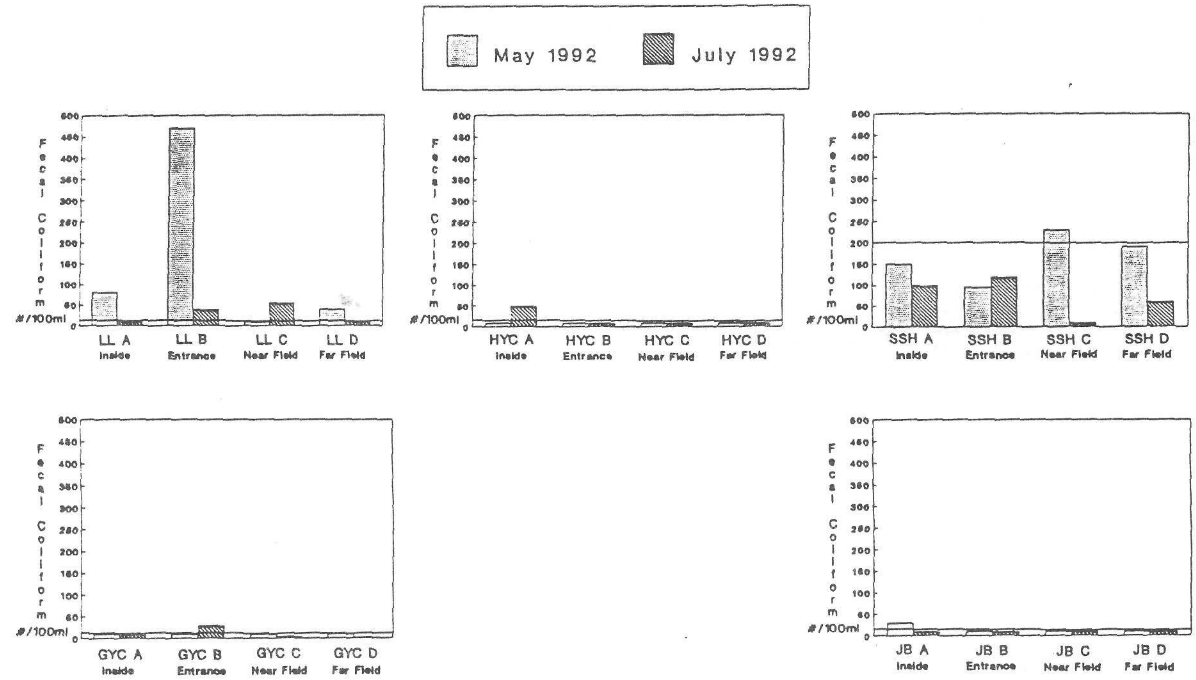

Figure 4. Fecal coliform levels measured at all marina sites. Grid line at 14 and 200 (#/100 ml) indicates the State water quality standard for the stream segment in which the marina is located.

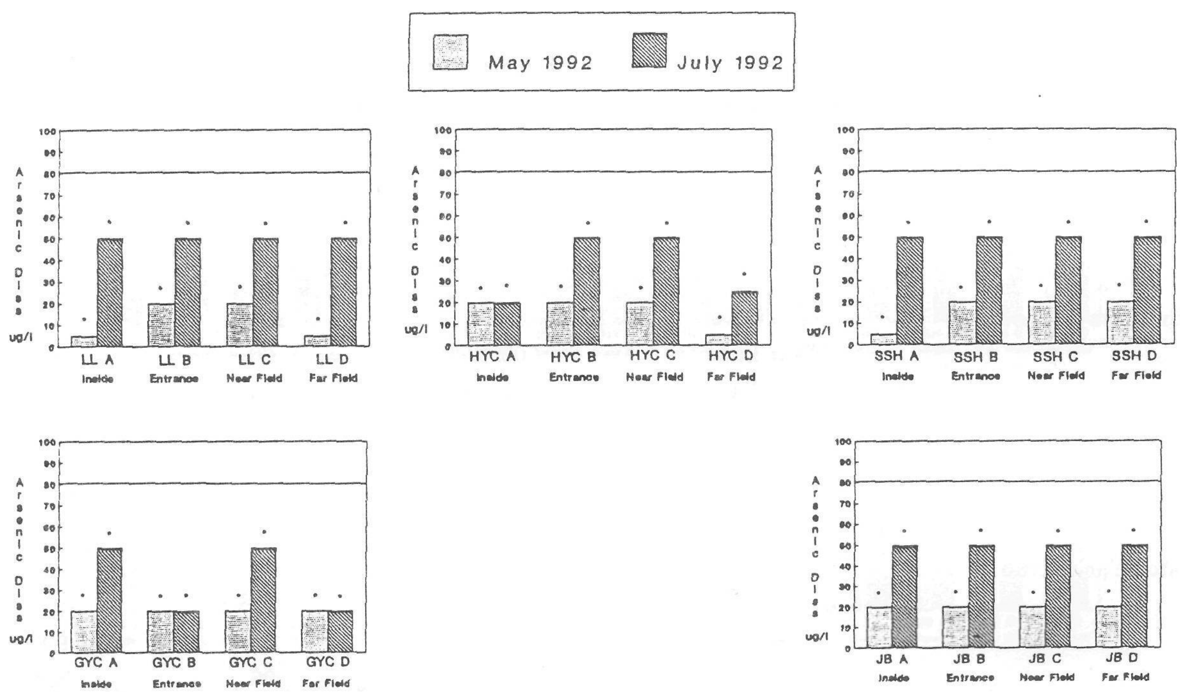

Figure 5. Dissolved arsenic levels measured at all marina sites. Grid line at 78µ/L indicates the marine chronic criteria for arsenic. Bars with "" represent values reported as less than lab detection limits.*

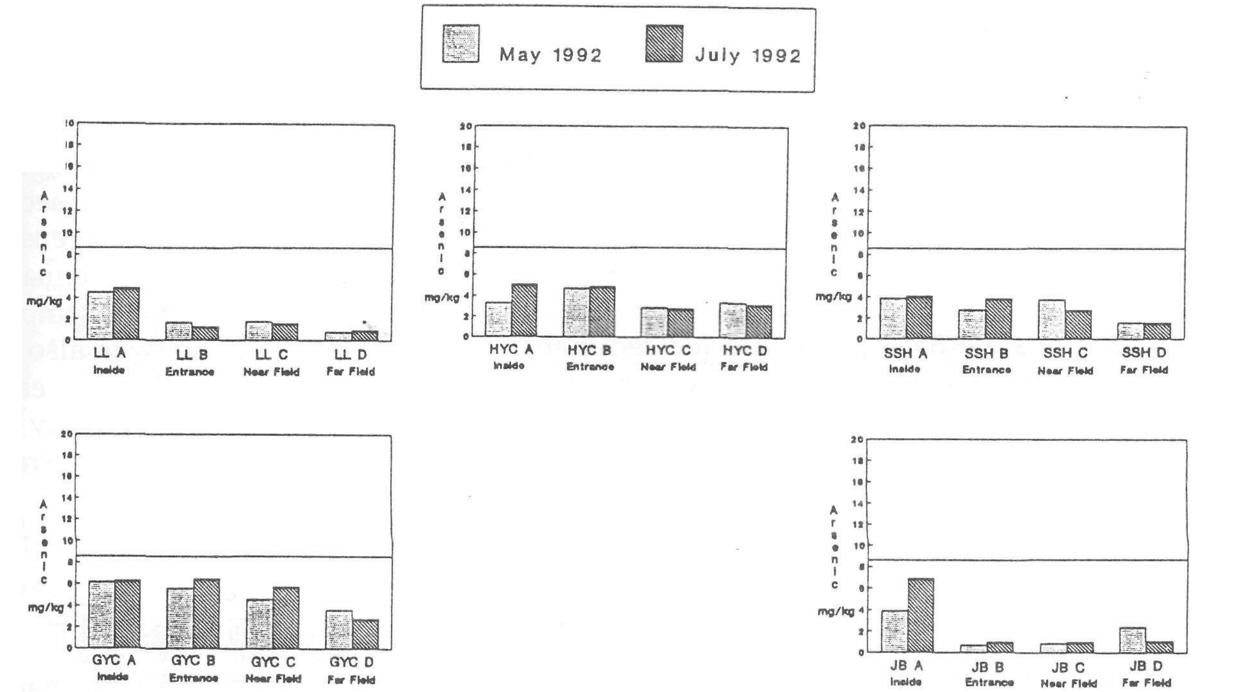

Figure 6. Arsenic levels detected in sediment samples at all marina sites. Grid line at 8.6 mg/kg indicates the 85th percentile for values in the TWC database for sediment samples in estuaries. Bars with "" represent values reported as less than lab detection limits.*

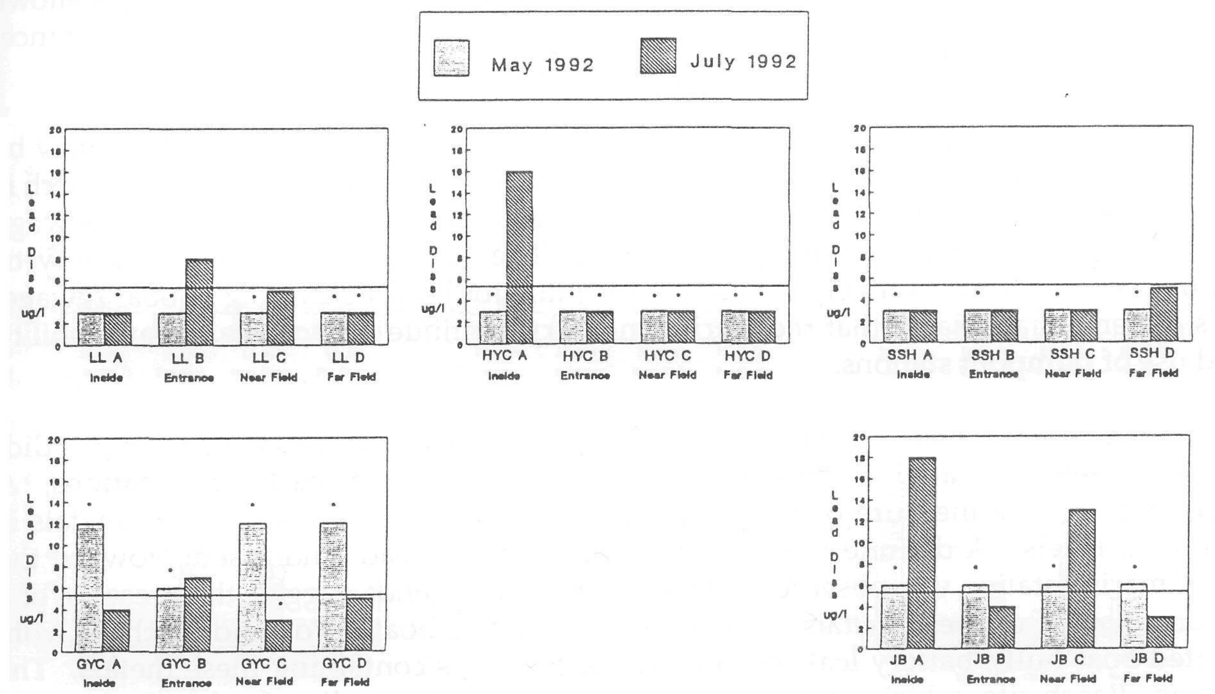

Figure 7. Dissolved lead levels measured at all marina sites. Grid line at 5.6 μg/L indicates the marine chronic criteria for lead. Bars with "" represent values reported as less than lab detection limits.*

the observed high dissolved lead levels. It is unknown whether maintenance dredging has recently occurred at this site.

Dissolved copper levels appeared to vary seasonally and exceeded state chronic and/or acute criteria at various stations throughout the survey period (Fig. 9). A higher number of exceedances occurred during July 1992. Dissolved copper also exceeded acute criteria at two different stations during each season (Fig. 10). There was a general increasing trend of dissolved copper levels toward the inner stations at the Jamaica Beach, South Shore Harbor, and Lafayette Landing marinas. Many sediment samples exceeded the state 85th percentile for sediment copper (Fig. 10). There was also an apparent increasing trend of lead contamination toward the inner stations of each marina. This suggests that long-term accumulation of lead in sediments may be occurring at these marinas. The least contaminated sediment was collected from Jamaica Beach.

Conclusions

Based on these preliminary results, it appears that most water quality impacts associated with marinas are localized within the immediate vicinity of each marina. Dissolved oxygen levels were generally depressed within the marinas. This was most severe at the Jamaica Beach finger canals and at South Shore Harbor. This phenomenon was least severe at the more open designed Galveston Yacht Club and Houston Yacht Club, which employ bulkheads that do not extend to the bottom. This design allows water to enter the marina from below the bulkhead and also at the marina entrance. The other facilities primary flushing corridor is through their main entrances.

High fecal coliform levels observed at far-field stations in Clear Lake marinas may be associated with other domestic point sources previously mentioned. Further research is needed to separate the effects of these two (recreational vessel sewage versus sewage treatment plant) effluents on water quality. The expansion of the availability of pumpout facilities should help reduce the potential for illegal dumping of boat sewage. It is extremely advisable that the marina industry continue to increase the availability and use of pumpout stations.

Spatial trends in dissolved metals were difficult to ascertain. Dissolved copper did, however, seem elevated at the Houston Yacht Club and Jamaica Beach locations. A more appropriate measure of long term accumulation and trends in heavy metals is sediment levels. A definite trend of increasing copper, lead, and arsenic toward the inner marina station was observed at most sites. These trends suggest the presence of a chronic source of these metals. These sources include boat yards and leaching from treated boat hulls, battery leakage, and use of products containing these metals. The Jamaica Beach site, which possesses the least number of wet slips, is also the location that possesses the least amount of sediment metal contamination. It may be that the higher number of treated boat hulls that are actually in the water contributes a large proportion of some of these metals (e.g., copper). The lack of circulation may also

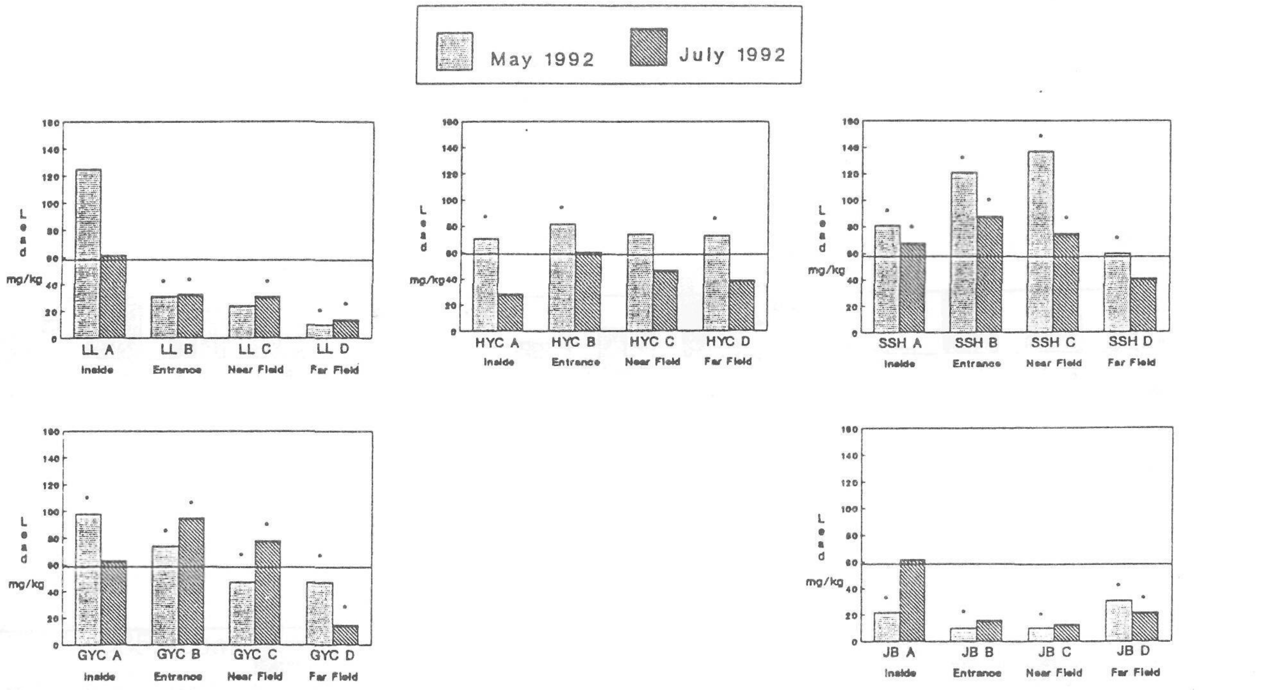

Figure 8. Lead levels detected in sediment samples at all marina sites. Grind line at 58 mg/kg indicates the 85th percentile for values in the TWC database for sediment samples in estuaries. Bars with "" represent values reported as less than lab detection limits.*

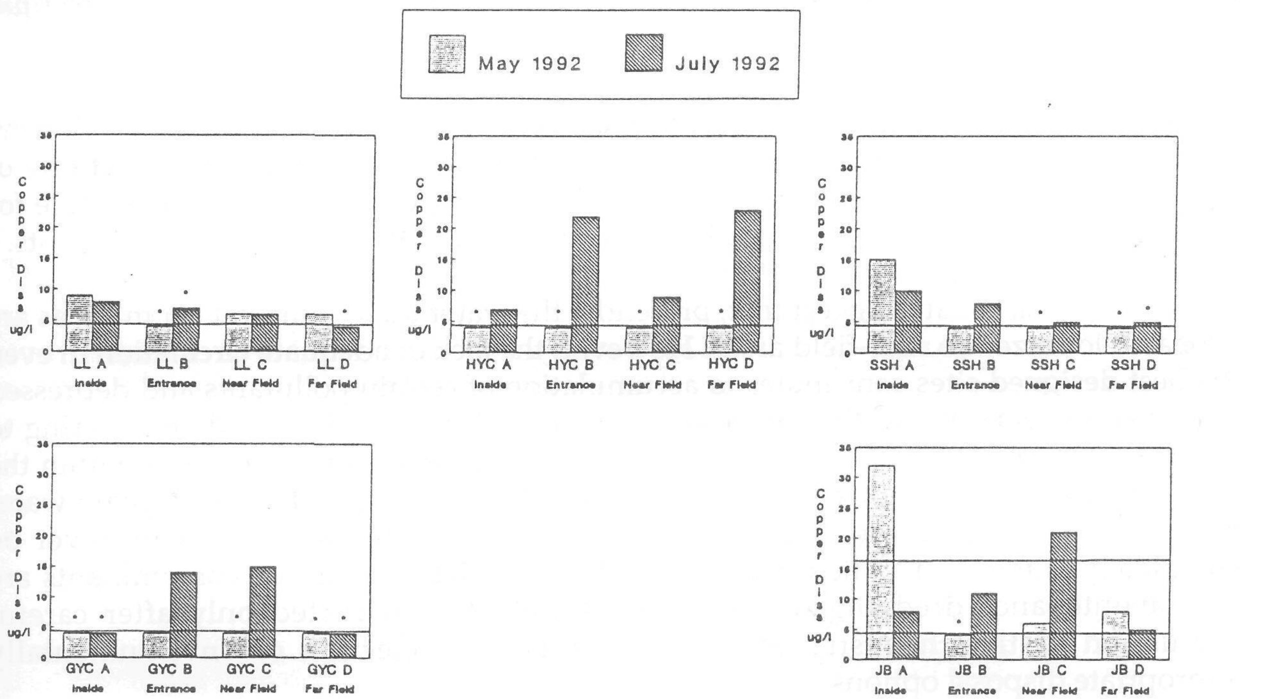

Figure 9. Dissolved copper levels measured at all marina sites. Grid line at 4.37 µg/L indicates the marine chronic criteria for copper, and the line at 16.27 µg/L indicates the marine acute standard. Bars with "" represent values reported as less than lab detection limits.*

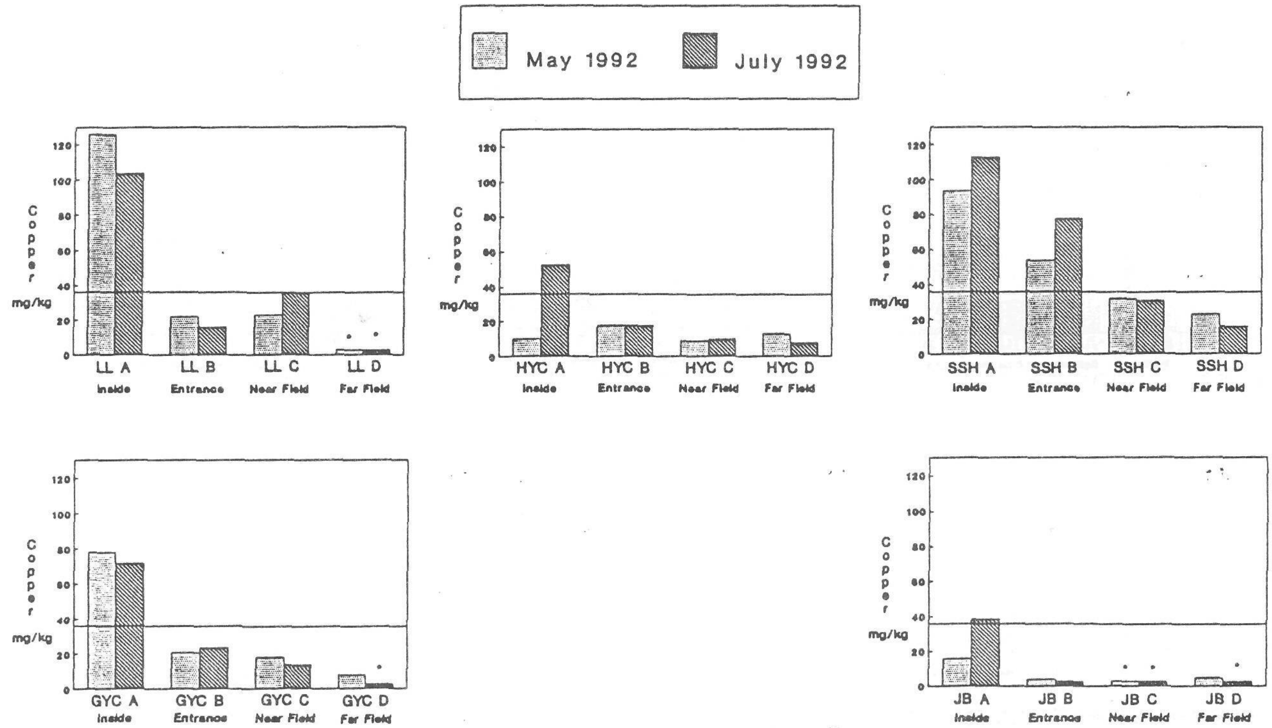

Figure 10 Copper levels detected in sediment samples at all marina sites. Grid line at 34.0 mg/kg indicates the 85th percentile for values in the TWC database for sediment samples in estuaries. Bars with "" represent values reported as less than lab detection limits.*

contribute to the precipitation of these metals from the water column into the sediment. Preliminary tide data suggests that little flushing occurs in the inner portions of marinas. This would lead to stagnant water conditions, which are more conducive for coagulation and precipitation of particulate and dissolved metals and other pollutants.

These preliminary data suggest that, presently, the water quality impacts of marinas are probably localized to near-field areas. However, the lack of adequate circulation in even the best designed sites contributes to accumulation of certain pollutants and depressed dissolved oxygen levels. Further research is needed in hydrology and engineering to determine optimum designs that promote flushing of stagnant water areas within the marinas. This may include the use of aeration and/or pumpage of these stagnant water zones, which may be necessary since the use of biocides will probably never be completely eliminated. The implications of accumulated sediment contaminants are that maintenance dredging of these sites should be conducted only after careful evaluation of the chemistry of the sediments and selection of environmentally appropriate disposal options.

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U.S. Geological Survey's National Water-Quality Assessment — Preliminary Study Plans for Data Collection in the Trinity River Basin

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In 1991, the U.S. Geological Survey (USGS) began implementation of a National Water Quality Assessment (NAWQA) program. The long-term goals of the program are to describe the status and trends in the quality of a large representative part of the Nation's surface-water and ground-water resources, and to provide a sound scientific understanding of the primary natural and human factors affecting the quality of these resources. A major component of the program is study-unit assessments, which will address local and State issues and comprise the principal building blocks for regional and National assessments. The 60 study units that comprise the program are hydrologic systems, which include parts of most major river basins and aquifer systems in the Nation. Planning, literature searches, and analysis of existing information have been in progress since implementation of the program.

An intensive data-collection phase began for 20 selected study units in October 1992 and will continue for three years. Next, a six-year, limited data-collection phase will be conducted. The program will cycle between the two phases as long as there is National support for the program. The current data-collection phase will focus on nutrients and pesticides in streams and aquifers. Water samples, bed sediments, and tissue of aquatic organisms will be collected and analyzed for target constituents. Ecological surveys and habitat measurements will be conducted to support and to provide additional information for the water-quality assessment. The Trinity River basin is among the first 20 NAWQA study units under the full-scale implementation plan.

The study plan for the Trinity River basin is designed to emphasize water-quality monitoring in streams and aquifers where the environmental settings have natural and human factors that are likely to concentrate nutrients and pesticides in surface water or ground water. Land use is considered to be one of the most important human factors. Of the many land uses, urban and suburban areas and farms are believed to have the most significant effects on nutrient and pesticide concentrations.

The stream-monitoring network will have 12 fixed sites; seven are *indicator* sites where the watershed has a rather uniform environmental setting, and four are *integrator* sites where the watershed has multiple land uses, diverse cultural and physical settings, or point sources or any combination of these. Sites in the network are located at USGS streamflow-gauging stations so that water-quality conditions can be related to flow, and constituent loads can be calculated. Water-column data will be collected for two years on a fixed schedule and during runoff events, especially those occurring in seasons when fertilizers and pesticides are being applied in the watershed. The water-quality parameters include: physical characteristics, common inorganic constituents, nutrients, organic carbon, and suspended sediment. Hydrologic parameters include stream stage and discharge. Two sites are on tributaries to the Trinity River in intensive farming areas and one site, on the mainstream near Dallas, also will be sampled for pesticides for one year.

A survey of bed sediment and aquatic animal tissue will be conducted for the stream monitoring network and for about 20 sites in addition to the 12 fixed sites. About one-half of the sites were surveyed during the fall of 1992 and the remainder will be surveyed during the fall of 1993. The very fine particles in bed sediment will be analyzed for trace elements, semivolatile organic compounds, organochlorine insecticides, and complex organochlorines. Dioxins and furan concentrations in very fine bed sediments will be determined at a few sites. Target taxa for tissue samples are corbicula and carp. Whole body samples will be analyzed for the same general constituents as the bed sediment. Ecological and habitat surveys will be conducted annually at about eight of the fixed stations. The ecological surveys will identify and count the occurrence of aquatic species, including fish, invertebrates, and algae. The habitat surveys will describe physically the ecologically important characteristics of a reach at a station.

Topics for planned synoptic surveys and research include: (1) metals and organic compounds in Lake Livingston sediments; (2) streamflow gains and losses in tributaries; (3) sources of salinity in tributaries; (4) occurrence of pesticides and nutrients during the growing season in streams traversing urban, suburban, and agricultural areas; (5) sediment accumulation and chemistry in selected reservoirs; (6) quality of irrigation return flow during the growing season in rice farming areas; (7) quality of urban storm water runoff for several relatively small and large watersheds; and (8) water budgets for the basin.

The aquifers will be monitored with networks of wells that will be grouped for three types of water-quality surveys or studies. Wells in the networks will be located in the Trinity Group aquifers, the Woodbine aquifer, the Carrizo-Wilcox aquifer, and the Gulf Coast aquifer. One survey, a study-unit survey that is regional in scope, will be conducted in the area underlain by aquifers in the Trinity Group, the Woodbine aquifer, and the Carrizo-Wilcox aquifer. In each of these three aquifers, a survey will be conducted by sampling many wells in the outcrop area and a few along a profile extending down gradient, which usually is downdip. A second survey will be conducted in each of the four aquifers where a targeted land use occurs in the outcrop area. Wells in this survey will be shallow and used to study the relation between the quality of shallow ground water and land use. Aquifers and associated land use combinations include:

Trinity Group aquifers	Forested and rangeland Improved pasture
Woodbine aquifer	Urban Suburban Forest and rangeland
Carrizo-Wilcox aquifer	Forest and rangeland Improved pasture
Gulf Coast aquifer	Rice farming Cattle ranching

Finally, a flowpath study will be conducted with a subset of surveyed wells in the urban area of the Woodbine aquifer. In this area, the ground-water flowpath of interest is from a recharge zone to a discharge area, which is expected to be a small stream. Several wells will have to be installed to adequately study these water-quality changes along the flowpath. In general, 20-40 wells will be included in each survey or study in each aquifer. However, many of the wells will be used for more than one survey. A total of about 200 wells will be sampled. Sample analysis will include common inorganic constituents, nutrients, major metals and trace elements, radiochemistry, and several classes of organic compounds common to urban and agricultural settings. Water from some of the wells also will be analyzed for constituents that are useful in estimating the age of ground water.

Surface-water and ground-water interaction will be assessed mostly by synoptic surveys along small streams where land-use surveys are to be conducted. Shallow wells near the streambed will be installed to measure the expected rapid water-quality change across the stream bed. These studies will be concentrated in urban and suburban settings.

The Trinity River basin is a major influence on Galveston Bay because it has about 75 percent of the drainage area and contributes about 50 percent of the inflow to the bay. Considerable information on the inflow from the Trinity River basin is necessary to develop plans to manage the resources of Galveston Bay. The Trinity River basin NAWQA study will collect additional water-quality data and improve the scientific knowledge and understanding of water quality in the basin to support these and many other efforts.